

Fault diagnosis and its application in HVAC facilities management*

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Abstract: This paper explains the technology and method of fault diagnosis in HVAC facility management. The characteristics of HVAC facilities are studied, and the methods for diagnosis are classified and summarized. A scheme of fault diagnosis is put forward. The strategies for diagnosis are presented. At last, some practical examples for fault diagnosis are discussed.

Keywords: HVAC systems; fault diagnosis; diagnosis models; fault tree; expert system

1. Introduction

At present the monitoring and diagnosis of facility condition is a fast developing technology in China and in other countries as well. With the popularity and rapid development of information and network technology, digital communication, and so on, it is possible to diagnose and to predict fault. With the progress of HVAC facility performance in building, facilities become more and more complex and it is obvious to need methods for fault diagnosis. When facilities are in abnormal, the repair time can be reduced and the system can be improved by using fault diagnosis technology to monitor the running state of facilities. As far as trouble-repair, trouble-prevention and trouble-saving are concerned, it is necessary to study and employ fault diagnosis technology. Especially fault prediction is more meaningful than simple fault diagnosis. Based on the past and present conditions of facilities and its running trend fault prediction and effective corrective measures are available, then severe accidents could be avoid. And it is necessary to research fault diagnosis theory and method, to make those results be put in practical projects and it is necessary to develop the corresponding expert systems.

The objective of fault diagnosis is to make facilities working normally, to avoid unexpected accidents and ensure system running normally. The role of fault diagnosis is to monitor facilities' conditions, whether normal or not, The role of fault prediction is to govern the system measurement and its repair.

2. Method and technology of fault diagnosis

Based on classificatory strategies, various input /

output parameters of HVAC systems can be classified by a classificatory system, in general, diagnostic results could be given. Fault tree and expert rule are classification methods in common use. There is another classificatory method, in which system model is used to predict possible faults of the system. It is established on the basis of normally running state and known fault conditions. Then it can compare the predicted parameters with measured parameters and use the compared results as gist of classification. The latter method is more difficult, because higher accuracy and smaller error of the model are needed. By monitoring running parameters, such as, temperature, air volume and power consumption, it is possible to alarm fault in real-time. For example, these parameters, running state of fan, filter condition in air-conditioning system, delivered air temperature, air volume of air-conditioning unit, temperature and pressure of chilled water, vapor pressure in boiler, pressure of condenser, temperature and humidity in air-conditioning room, need to be monitored.

- Fault diagnosis methods mainly include:
- method based on fault mechanism,
- those based on signaling process and feature abstraction,
- fuzzy diagnosis theory and method
- fault tree diagnosis theory and method, and
- fault diagnosis expert system.
- Common techniques of fault diagnosis include:
- Vibrational noise monitoring technology (vibration sensor, recording and analysis),
- temperature monitoring technology (infrared detecting temperature, infrared thermal image),
- stress strain monitoring technology (including

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displacement monitor),

- non-destructive monitor (ultrasonic technology, radio frequency flaw detection), and
- electric parameter monitor (gaseous leakage monitor, composition analysis of liquid and gas, insulation resistance)

3. Fault characteristic and classification in HVAC system

Faults in HVAC systems may be classified in hard fault and soft fault. Its influence may be global or local. Hard fault is the fault comes from apparatus damage or failure, such as shutdown of fan, breakdown of belt, lose of data or bad output of data from sensors and obstruction of valve or the faults. Based on time sequence of fault occurrence, this kind of fault is easy to detect, because it is abrupt and evident. Soft fault is the fault that the performance of facilities and apparatus is dropping or in partial failure, such as scaling of fan coil (obstruction of fan coil), leakage of valve and drift of instrument. In general, it is difficult to determine a soft fault because it happens gradually and its sign is not obvious, especially at its early stage. To some extent, soft fault is more harmful than hard fault. So it is meaningful to prevent soft fault in advance by monitoring facilities conditions.

4. Fault Characteristic in HVAC facility

In the course of running HVAC facilities, the faults of system are mainly unorganized failures. So they are called stochastic and the process of fault occurrence is a non-stationary stochastic process with time. From the view point of building structure, these facilities consist of various subsystems and different elements. This kind of structure is layered. So fault existence is also hierarchical. Building system consists of many associative subsystems and some faults of subsystem may be resulted from their associative systems or segments, which is called as the propagation of fault. Fault comes from different positions may be a facility fault or a sensor fault, may be a hard fault or a soft fault. But these faults are often presented with interactive affection, which increase the complexity of fault diagnosis in HVAC system.

5. Diagnostic models and structure of diagnosis system

Based on the analysis of fault mechanism and the particularity of HVAC systems, diagnosis models in

HVAC systems may be divided into three categories: conventional routine diagnosis based on fault tree, regular diagnosis based on expert system and fault pattern diagnosis based on neural net pattern recognition. The structure of diagnosis system is shown in fig. 1.

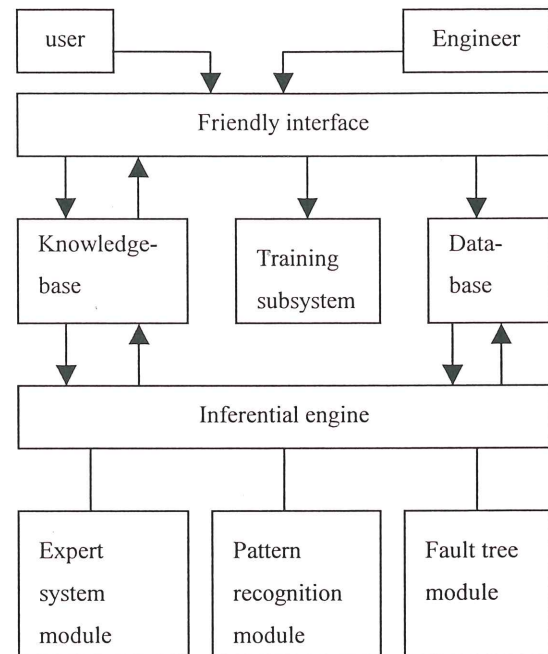


Fig. 1. The structure of diagnosis system

6. Schemes of fault diagnosis in HVAC systems

There are two main methods of fault diagnosis in HVAC systems. One is online method. According to real-time monitoring of facilities conditions, real-time fault detection and diagnosis algorithm, fault information is available, including the extent of fault, which module the fault belongs to, fault position and fault alarm. The other one is offline method. By using computer-aided decision making system, fault can be timely determined and effective repair scheme can be obtained.

6.1 Expert system diagnosis module based on knowledge

Expert system diagnosis module and expert system knowledge fault base can be increased, revised and innovated during the running of the system experience and knowledge are accumulated and renewed, reliable fault diagnosis is attained and some rules are determined to be imperfect or errors.

Expert system diagnosis module consists of knowledge acquisition system, knowledge base,

inferential engine and input/output system.

6.2 Fault tree diagnosis module based on rules

Basic fault diagnosis tree is based on expert knowledge and engineer experience. User can select suitable fault diagnosis tree to execute fault diagnosis.

Fault tree analysis is an effective tool to diagnose fault in complex system. This method is efficient and reliable. For example, according to the fault phenomenon, the module can trace downward, and detect corresponding nodes and branches until the origin or the reason of fault has been found then the handling strategy can be attained.

6.3 Pattern recognition module based on artificial neural net BP algorithm

This module is composed of BP improved algorithm net, neural structure parameter and inferential diagnosis. Its main goal is to achieve the pattern recognition and fault diagnosis.

By comprehensively using expert system diagnosis and fault tree diagnosis, for those faults, already have happened, can be effectively solved. But for those faults, which haven't emerged, will be helpless. The reason is that there is no corresponding diagnosis knowledge in existed knowledge base. Artificial neural net (ANN) is a reliable method to resolve this kind of problem. ANN has the ability to study new knowledge and be trained. Consequently, the new knowledge can be added to the original expert knowledge base. Basic samples of ANN come from the actual faults, which can be obtained from fault mechanism analysis or expert experience, and can be increased, deleted and innovated during its application.

7. Examples

The technology of fault diagnosis in HVAC facilities includes: fault detection and fault diagnosis. Two main route ways are evermore used, they are divided into downward way and upward way. The downward way is a method to gradually diagnose fault from main system to subsystems, that is to say, from air-conditioning system to supply-air system, fresh-air system, exhaust-air system, chilled water system and cooling water system, etc. The upward way is a method to diagnose the local facilities or particular element and to detect specific temperature, current, pressure, resistance, air volume, and so on.

The goal of fault detection is to attain the abnormal data of running parameters in building facilities and based on these data to determine whether the facility is normal or is failing. Abnormal conditions of facilities may happen during the entire process or under particular circumstances. Fault diagnosis is more important and more difficult than fault detection. At present, the commonest method is to compare the running data with the normal data in database. Table 1 lists out the main parameters of screw type chillers in normal status. Based on these data, it is possible to diagnose the common faults of chillers. For examples, by detecting the pressure of suction and discharge, faults in these locations can be found; the conditions, such as super high temperature of condenser entering water or decrease of water flow, condenser scale, pump fault and lack of refrigerant, can lead to the reduction of exhaust air pressure.

Fault diagnosis in HVAC systems is also executed by monitoring the running characteristic of their facilities. Diagnosis methods may be classified into two kinds. One is to monitor the whole running state. The other is to set some detecting criteria. Take timing data comparison, for example, monitoring data are compared with the data of facilities in typical fault database. Using tracing system of energy dissipation, conditions of consuming energy can be monitored and be compared with the normal running data. It is possible to determine the working state of facilities by comparing coefficient of performance (COP). It is possible to deduce exchange coefficient of heating facility by comparing user's bill. Downward way is to diagnose the local facilities and elements, such as temperature rise of motor and response time of transitional process in control loop. Dissipated energy bill, cost computation and user satisfaction level can all be as reference index. For example, air supply fan is easy aging and its elements are easily damaged. When it is loosened, fan will be slow and then flow rate decreases. Thereby, the indoor environment is influenced, even fire is led to. In 1987, in a building at a university of politics and law in Chongqing, a fix screw of electrical machine in air-conditioning system was loose, which made belt become loose and lead to air volume decrease. At the same time, electrical warm-up unit normally worked, which led to piping superheat and fire happened. A LH48 air-conditioning unit was

burned up. On the other hand, fan belt of supply-air fan is also aging and damaged. Its breakdown and loosen can make rationale speed slow and air flow reduced, which lead to the indoor temperature and humidity worse. Take a mall for example, there should be 3belts in 1# air-conditioning unit. But one belt was cracked and the others were aging. So the air flow rate was reduced from 33 000 m³/h to 10 342 m³/h.

Table 1. main parameters of screw type chillers under normal running state

No.	Name	Range
1	Chilled outlet water temperature	5°C to 7°C
2	Chilled intake water temperature	10°C to 15°C
3	Cooling outlet water temperature	35°C to 37°C
4	Cooling intake water temperature	≤32°C
5	Condenser entering/leaving water temperature	4°C to 10°C
6	Evaporator entering/ leaving water temperature	4°C to 10°C
7	High pressure	1.2 MPa to 1.7 MPa
8	Low pressure	0.38 MPa to 0.5 MPa
9	Discharge temperature	60°C to 100°C
10	Suction temperature	5°C to 12°C

8. Conclusions

There are various faults in complex HVAC systems. Faults are very harmful, not only lead to the increase of energy dissipation, degrade the indoor air quality and shorten the life of facilities, but also can increase hidden danger. Thus fault diagnosis is as important as facilities work in order to ensure system to run normally. In practice, it is very difficult to find out faults in HVAC system only by manual labor. So it is meaningful to develop auto-detection and diagnosis of fault in HVAC facilities management.

Fault diagnosis in HVAC field is a new subject. At present, it mainly engages theory and method study. It concerns many disciplines, such as fuzzy mathematics,

statistics, building thermal engineering, HVAC, auto-control, communication and computer technology. It includes fault mechanism of facilities, fault diagnosis theory and method, signal processing and computer technology. It is not only a theoretical task but also a practical engineering problem. Therefore, fault diagnosis is not easy. But fault prediction is more difficult than fault diagnosis. Fault prediction advances the repairing means from prevention to prediction. So it is more meaningful to study the method of fault prediction. But it is necessary to perfect the database of fault diagnosis and prediction.

This paper presents the structure of a diagnosis system. Based on the total function and practical diagnosis knowledge, fault tree, expert system and pattern recognition are comprehensively used. Not only expert and engineer's knowledge and experience on fault diagnosis are used, but also BP algorithm of neural net is employed. By studying and training, the system can diagnose and analyze faults, which didn't happen in the past. With the development of computer, electronic and communication technique, fault detection and diagnosis in HVAC systems will be in practice in the near future.

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